Comment
Greenwood Telecommunications Consultants LLC Denver, CO

On Matter of Out of Band Emissions (OOBE) Interference in GNSS Bands

Re: DA 13-1717, IB Docket Nos. 12-340, 11-109; IBFS File Nos. SAT-MOD 20120928-00160, -00161; SAT-MOD-20101118-00239; SES-MOD-20121001-00872; RM-11681; WT Docket No. 12-327

Introduction

A new, feasible OOBE standard for protecting the GNSS band is important for at least two reasons: 1) it is important to make OOBE rules as future-aware as possible since they are infrequently changed, less than every 10-20 years, and 2) the rise in wireless and GNSS devices, their density in both number and proximity is virtually undisputed. Thus a rise in OOBE interference can reasonably be expected and should be forestalled before it becomes an intractable field problem. LightSquared has offered a compelling proposal[1] that the FCC has asked for comment, which is offered here by Greenwood Telecommunications Consultants ("Greenwood"), Denver, CO. Greenwood is a general telecommunications and wireless management and technology consulting firm specializing in wireless, GPS and radio technology and engineering.

Greenwood filed comments in the 2012 DISH Network NRPM[2] regarding the Commission's query regarding OOBE performance in the context of avoiding interference in the GPS L1 band, especially devices expected to operate in the proposed DISH Network S Band at 2GHz converting it for Auxiliary Terrestrial Component (ATC) operation. In that proceeding Greenwood advocated that OOBE be modernized to avoid increasing exposure unduly to the GPS/GNSS[3] band by raising OOBE rule to not exceed -105dBW/MHz for all mobile devices with a carrier frequency near the GNSS L1. By extension we advocate here for sake of consistency that OOBE rules also be made for all GNSS segments in the L Band (including the L1, L2, L5 and E6 band segments between 1159 and 1610 MHz) that follows a modern 1 meter device-to-receiver separation criterion. Greenwood believes both OOBE and adjacent band interference should be resolved together in order to enable robust crowded spectrum operations and avoid problems as seen in the recent LightSquared GPS controversy.

The Commission requested comments and analysis regarding a submission by LightSquared[4]. Our view is that the submission by LightSquared offers a serious analysis and addresses the matter of OOBE specifications responsibly for the GNSS L1 band. Their submission appears to advocate setting a higher bar much higher than existing MSS OOBE rules (present OOBE rule is -70dBW/MHz) as well as other devices operating in the L Band including new PCS mobile devices, some operate closer to GNSS bands than before. The LightSquared submission sets forth that a 1 meter device separation as an appropriate condition for densely deployed wireless and GNSS equipment. We agree and this separation criterion

[1] Link at http://apps.fcc.gov/ecfs/comment/view?id=6017458747
[2] Link at http://apps.fcc.gov/ecfs/document/view?id=7021918561 especially pages 15,16
[3] From this point forward will be referred to as GNSS, Global Navigation Satellite Systems
[4] Link at http://apps.fcc.gov/ecfs/document/view?id=7520936682

which also follows broader industry practice, including use by the wireless 3GPP standards community for setting advance cellular communications interference performance.

Though credible use cases were presented in the LightSquared OOBE submission[5], it seems hard to assume anyone can ascertain comprehensively the possible use-case factors or conditions that could affect OOBE performance. New innovations, changing device designs, rising density of devices, use in automated and sensor network systems, and finally, changing consumer usage behaviors all make use of "typical" or "average" patterns of use difficult to standardize. Thus we were taken by the number of stacked assumptions and statistical assertions that while taken one at a time appear reasonable, the cumulatively picture is not always as predictable as the sum of the parts since certain factors are not necessarily statistically independent nor does the result reach a sufficiently small incidence to be deemed an immaterial impact. It is also difficult to enforce rules drawn with so many factors and statistical definitions if the object is to move toward practical, widely observed OOBE rules.

Though it is a convention to factor blocking for OOBE analysis -- that is estimate the radio path loss between devices -- often there are cases where there exists no human blockage present in the radio path. Data usage has eclipsed voice, and even for voice ear buds are a common way to avoid holding the device at the ear. These are just two cases before considering "Internet of Things" and other future radio applications where there are no humans surrounding pervasively deployed wireless or GNSS devices thus are just automated systems that potentially will have only unobstructed RF paths between them. Thus the authors advocate simplifying test conditions and using deterministic factors to the fullest extent to remove doubt and increase robustness economically.

Without this approach, 90% of cases could be below peak OOBE power but there is little comfort for the 10% of cases at greater power especially when 10% can represent in aggregate terms millions of devices. Also possibly missing in the analysis using averages is the positive correlation between rising data service use and mobile uplink power due to more demand to serve increased throughput. Where the averages stop moving is anyone's guess.

While thorough in many respects, we believe the LightSquared submission has two analytical errors regarding setting a proper OOBE performance threshold. Though it was attributed to another source, the GPSIC[6], we disagree that the OOBE onset threshold should be set as high as -174 dBm/Hz for GNSS. This figure is commonly known to be the classic receiver thermal noise floor (assuming a perfect or 0 dB noise figure). When combined with OOBE power from a nearby transmitter, following receiver design practices and test conventions, it is desired that the aggregate noise not rise by more than 1 dB. That threshold occurs where the OOBE is 6 dB below thermal noise plus a figure to account for the receiver noise figure, commonly assumed to be about 2 dB in many GNSS receivers. This produces a pre-OOBE added threshold of -172 dBm/Hz. A 1dB noise-rise threshold attributable to OOBE is therefore 6 dB below this figure, thus the correct figure we believe properly sets the OOBE floor at a lower figure than

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[5] Ibid 1

[6] July 15, 2013 Ex Parte Submission by LightSquared, Re: Notice of *Ex Parte* Presentation*; IB Docket No. 11-109; DA 12-1863, IB Docket No. 12-340; IBFS File Nos. SATMOD-20101118-00239; SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; RM-11681; WT Docket No. 12-327*, page 7

was cited, or -178 dBm/Hz.   A 1 dB additive noise containment margin appears reasonable and also contains the GNSS receivers highest C/No reduction to be also within 1 dB. This is a conventional interference design margin for receiver desensitization in both communication and GNSS receivers respectively.

Second, we disagree with the assertion that OOBE compliance should be based only on a statistical “average” output power or transmission duty cycle. In contrast to communication receivers, GNSS receivers may be in different states or modes for various reasons. Intermittent noise affects receiver performance with an impact that is similar to continuous noise sources. Some receivers require fast acquisition or re-acquisition (ostensibly to conserve battery power or prioritize CPU load are just two factors) rather than be designed to continuously tracking GPS/GNSS satellite signals. While receivers that continuously track satellites also mitigate impact of extraneous noise (due to low tracking bandwidths) and at the margin will also mitigate intermittent duty cycle sources of interference. However, this protection cannot be necessarily assumed to exist exclusively across all GNSS receivers such as receivers initially acquiring or re-acquiring which in that mode operate without benefit of continuous tracking. A classic case are Personal Navigation Devices (PND’s) which are used occasionally and must acquire at relatively high C/No signal levels for some time prior to entering signal tracking mode.

More of concern is the assumption made that the mobile transmitter OOBE decreases on a dB for dB basis relative to the peak transmitter output power. The ratio of OOBE and peak transmission power is not necessarily a constant relationship. Modern ultra-low drain high efficiency mobile transmitters are designed to compress amplifier gain in order to conserve battery drain. Some transmitters use envelope following or control the voltage to the PA to save battery life at the expense of OOBE by operating the power amplifiers at optimum compression and nonlinear amplifier operation unfortunately can increase OOBE products.

Table I: GNSS OOBE Determination to Raise GNSS/GPS Receiver by 1 dB C/No

Determination of OOBE for 1dB loss in GPS C/No				Comment
GNSS Receiver Noise Figure		2.0	dB	
Receiver Noise Floor		-172.0	dBm/Hz	
Power allowed for 1dB desense		-178.0	dBm/Hz	
Coupling loss of GPS antenna		-5.0	dBi	Reference, based on TWG Cellular Sub-Group GPS antennas, includes polarization mismatch. Other antenna figures may apply.
Budget for misc. effects, measurement margin		2.0	dB	
Path loss at 1 m (1575MHz)		36.4	dB	
OOBE allowed at Tx		-134.6	dBm/Hz	
OOBE allowed at Tx dBW/MHz		**-104.6**	**dBW/MHz**	

Conclusion

Greenwood agrees with LightSquared’s one meter separation criterion, use of a consensus based portable antenna coupling factor such as the recent TWG Cellular Industry Sub-group determined, are appropriate parameters toward setting new rules for OOBE. We would however depart on use of statistical methods to reduce analytically the amount of projected or acceptable OOBE power. Averages are difficult to confirm, test, interpret and most of all enforce. As a practical matter we rely on OOBE in design conformance or compliance test processes. Therefore we recommend applying the fewest, fixed, and more deterministic parameters for OOBE rulemaking similar to those shown factors and values shown above. A measurement margin provides real-world factor, which we suggest be set at 2 dB to account for practical measurement uncertainty and other relatively minor testing effects.

The commercial feasibility of higher OOBE performance has to be assessed to ensure tighter performance as offered by LightSquared or others could be attained in such a way that is competitive and rules would not place a particular operator at a competitive disadvantage. Naturally, the interest of GNSS is to cope with a more crowded L Band OOBE environment arising both in and outside the traditional MSS sub-bands. We studied this using current state of the art mobile amplifiers and duplexer filter components to ascertain if -105 dBW/MHz is commercially feasible.

We found that there is feasibility technically and commercially for PCS, AWS-1 (see Appendix A) since these systems are farthest from L Band GNSS bands. Until it is settled, no one can categorically state with exactitude what duplex filter's attenuation of OOBE is until a paired downlink frequency will be for each LightSquared uplink which is subject to resolution of its proposal to operate downlinks in two distinct parts of the L Band [7]. However, given likely similar duplex frequency separation and operating environments to PCS, we reasonably project LightSquared could reach -105 dBW/MHz OOBE protection levels over most (to at least 1605MHz) if not all of the GNSS L1 band.

These conditions should be applied along with setting the OOBE transmitter to operate at its peak EIRP to ensure the ultimate test result protects "de-coupled receivers" (as used here, receivers that are not under design or operating control of the operator) that are close with reasonable certainty. The purpose of a deterministic test condition is not to create an arbitrarily worst case condition that implicitly locks in margin for one side; the purpose is to design a test condition that ensures greatest field compatibility consistent with the reality that there will be significantly more spectrum usage, higher device densities and more diverse use-cases.

This approach is even-handed. It avoids shifting an economic burden by solving the problem where it is least expensive to solve it, in this case inside the transmitter, since the receiver when exposed has no immunity against OOBE. In the converse interference case, adjacent band interference, the responsibility for compatibility primarily rests with the receiver manufacturers to prepare their receivers for expected adjacent band transmissions with known power level and frequency separation contours. The case for managing adjacent band interference is being addressed in other proceedings, however, this point is worth raising here since it makes little economic sense to improve OOBE without a parallel, concurrent process of improving receiver adjacent band interference (ABI). We surmise that future customers of both wireless and GNSS services are harmed if mitigation of transmit-side OOBE is not

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[7] As well known to many including the Commission, LightSquared is seeking terrestrial authorization within the NOAA Meteorological band combined with adjacent spectrum between 1670-1675MHz. It is also seeking other spectrum based on the "Lower 10 MHz" MSS downlink which is subject to complex discussions beyond the scope of this comment.

accompanied by increasing receive-side adjacent band interference rejection or blocker performance since they both arise from the same physical factor: shrinking distance between the receiver and nearby L Band transmitter(s).

For devices operating relatively far in frequency away from the GNSS bands, we recommend OOBE performance in GNSS frequencies be set or transitioned to reach -105 dBW/MHz inside the GNSS bands. This uniform specification should also be applied to devices operating between 700-2100MHz thus transmitting within 500MHz of any GNSS sub-band currently authorized between 1159 and 1610 MHz.

For terrestrial transmitting devices operating within approximately 25MHz of the GNSS L1 band edge, a common OOBE performance standard has to be more critically designed but is possible to achieve. We assessed feasibility to attain -105 dBW/MHz OOBE performance for services adjacent to the high side of the GNSS band, specifically uplink frequency bands covering the MSS, AWS-1, 1695-1710MHz as well as LightSquared's proposed ATC service which is proposed to operate on MSS-GEO two 10MHz wide uplink frequencies between 1626.6-1660.5MHz.

Our conclusion is that these services adjacent MSS, including the uplink bands that LightSquared proposes as terrestrial service uplinks, can attain OOBE performance level of -105dBW/MHz over the L1 GNSS band, certainly for the entirety of L1 band to at least above 1605MHz. Frequencies between 1605 to 1607MHz implicates several GLONASS satellites carrier frequencies, but the mass of GNSS satellites and GNSS L1 signals can be fully protected in our view provided OOBE of -105 dBW/MHz is met even if there were to be a reduced OOBE contour near the edge of the GNSS L1 band. In our view, this compromise could work so long as the OOBE at the upper margin of the L1 band is not excessive.

Though outside the scope of this proceeding, we believe current OOBE rules for the directly adjacent MSS services are woefully out of date (their most protective level of OOBE currently is -70 dBW/MHz, but the rules permit a sharp rise to -10 dBW/MHz at the 1610 MHz band edge) due to further "terrestrialization" of LEO services. One example is the latest proposal by Globalstar, a proposal to use the MSS band directly adjacent to GNSS for their Terrestrial Low Power Service (TLPS)[8]. This proposed service merits new study of the impact OOBE into the directly adjacent GNSS L1 band since it potentially adds a high number of wideband urban terrestrial mobile transmitters. This is a quite different profile than their current sparsely deployed LEO mobile satellite communication service. We believe this new consumer focused terrestrial service has significant implications for GNSS spectrum management and its interference ramifications should be addressed in a separate proceeding.

[8] Link at http://www.globalstar.com/en/ir/docs/Globalstar_Webinar_Presentation.pdf especially pages 11, 17, 22

APPENDIX A

To consider mobile production feasibility, we evaluate the maximum OOBE for the band based on commercial components at a similar frequency, using a commercially available PCS duplexer that is tuned to pass and reject mobile transmitter and receiver signals in the 1900 MHz band with 15 MHz duplexer separation. This band currently has the most devices (in the US) deployed closest to the GNSS L1 band centered at 1575.42MHz.

The following data and chart excerpt is from the Avago Technology duplexer filter Datasheet for Avago P/N ACMD 6125.

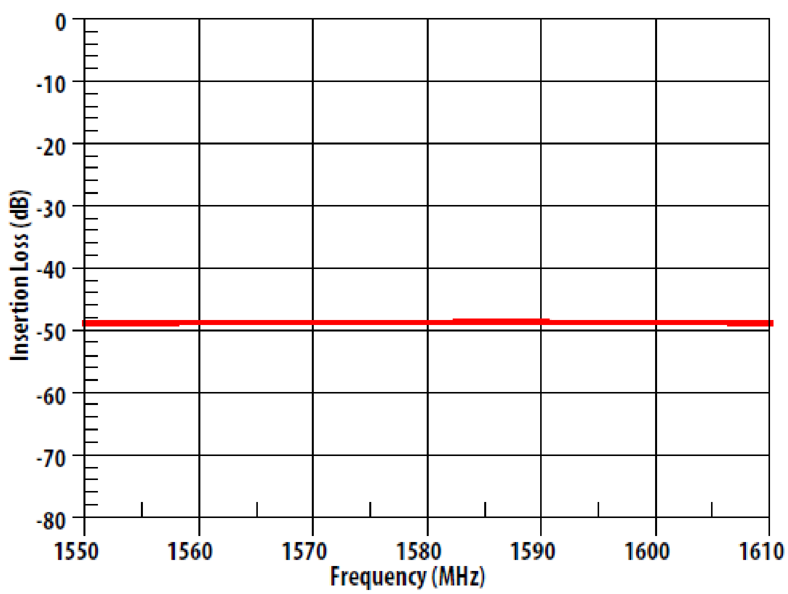

Figure 11. Tx–Ant Rejection in GPS/GLONASS Bands

Source: Avago Technologies Datasheet, Duplexer ACMD 6125

It is well known that transmitter spectra for frequency offsets close to the center frequency are dominated by the power amplifier non linearity. The dominant terms for this are the AM to AM conversion modeled by intermodulation (IM) effects from odd (i.e, 3rd , 5th, etc) orders superimposed to form a familiar tapered roll off power spectral shape surrounding the LTE wideband carrier. This OOBE estimation model results in spectral plateaus of the same bandwidth as the modulated carrier signal (in this case we used the widest 10MHz). Using classic odd-order IM calculations, we project that the transmitter at 16MHz below the proposed LightSquared mobile transmitter center frequency will be approximately -105dBW/MHz prior to entering the duplexer filtering.

The primary aim of the duplexer filter is to reduce the effect of the main and side lobes of the transmitter falling into the communication receiver pass band. Following state of the art practices, the rejection of transmitter energy should not impact receiver sensitivity by more than 0.1 dB in consumer cellular mobile products.

Duplexers are also designed to achieve high rejection outside the transmission band -- and in this commercial component shown here for PCS duplexer -- rejects about 50 dB in the GNSS band. We believe similar GNSS attenuation figures can be attained for MSS band devices such as LightSquared provided that the duplex separation is no less than 15MHz and insertion loss factors similar to PCS.

With wider frequency offsets, the OOBE estimated IM noise drops more, as the higher order IM terms dominate. Even without the benefit of the duplexer, for the lower LightSquared uplink (1626.5-1636.5MHz) sideband IM noise is close to -105dBW/MHz at the edge of the GNSS band only natural diminution of the PA sideband energy. Therefore, adding rejection from the duplex filter in the signal path just after the PA will drop OOBE products further, even for more compromised closer duplex frequency offsets. The OOBE estimation and sideband products are illustrated in Figure I below.

Figure I: OOBE Estimation of OOBE along upper region of GNSS Band Based on Commercial Duplexer Response Combined with LTE Signal Intermodulation OOBE Generation (between 1586.5 to 16465.MHz)